www.ijecs.in
International Journal Of Engineering And Computer Science ISSN: 2319-7242
Volume 5 Issue 12 Dec. 2016, Page No. 19392-19397

Power Quality Control of Nonlinear Load using Custom Power Devices

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1. ABSTRACT

A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a miss-operation of end user equipment's. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. The present work is to identify the prominent concerns in this area and hence the measures that can enhance the quality of the power are recommended.

This work describes the techniques of correcting the supply voltage sag, swell and interruption in a distributed system. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. A D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. Comprehensive results are presented to assess the performance of each device as a potential custom power solution. The STATCOM is applied to regulate transmission voltage to allow greater power flow in a voltage limited transmission network, in the same manner as a static var compensator (SVC), the STATCOM has further potential by giving an inherently faster response and greater output to a system with depressed voltage and offers improved quality of supply. The main applications of the STATCOM are; Distribution STATCOM (D-STATCOM) exhibits high speed control of reactive power to provide voltage stabilization and other type of system control. The DSTATCOM protects the utility transmission or distribution system from voltage sag and /or flicker caused by rapidly varying reactive current demand. During the transient conditions the D-STATCOM provides leading or lagging reactive power to active system stability, power factor correction and load balancing

Keywords: Distribution Static Synchronous Compensator (D-STATCOM), Voltage Dip, Distribution system, Custom power device, MATLAB/Simulink.

2. INTRODUCTION

One of the most common power quality problems today is voltage dips (voltage sag).A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0.5 cycles to 1 minute.

In a three-phase system a voltage dip is by nature a three-phase phenomenon, which affects both the phase-to-ground and phase-to-phase voltages. A voltage dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged.

Electric power distribution network becomes more increasingly important and plays an essential role in power system planning. This type of power systems has a major function to serve distributed customer loads along a feeder line; therefore under competitive environment of electricity market eservice of electric energy transfer must not be interrupted and at the same time there must provide reliable, stable and high quality of electric power. To complete this challenge, it requires careful design for power network Planning. There exist many different ways to do so. However, one might consider an additional device to be installed somewhere in the network. Such devices are one of capacitor bank, shunt reactor, series reactors, and automatic voltage regulators and/or recently developed dynamic voltage restorers, distribution STATCOM or combination of them.

Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc. are damaged. Hurt of this phenomenon in companies that dealing with information technology systems is serious. Nowadays, Custom Power equipment's are used for this purpose. DSTATCOM is one of these equipment's which can be installed in parallel with. Sensitive loads. This device mitigates the load voltage by Injecting necessary current to the system

3. PRINCIPLE OF OPERATION

The D-STATCOM is a three phase and shunt connected power electronics based reactive power Compensation equipment, which generates and /or absorbs the reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The AC voltage difference across the leakage reactance power exchange between the D-STATCOM and the Power system, such that the AC voltages at the busbar can be regulated to improve the voltage profile of the power system, which is primary duty of the D-STATCOM.The D-STATCOM employs an inverter to convert the DC link voltage Vdc on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source. The basic objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage. The operation of the D-STATCOM is as follows: The voltage is compared with the AC bus voltage system (Vs).

- When the AC bus voltage magnitude is above that of the VSI magnitude (Vc); the AC system sees the D-STATCOM as inductance connected to its terminals.

- Otherwise if the VSI voltage magnitude is above that of the AC bus voltage magnitude, the AC system sees the D-STATCOM as capacitance to its terminals.

- If the voltage magnitudes are equal, the reactive power exchange is zero.

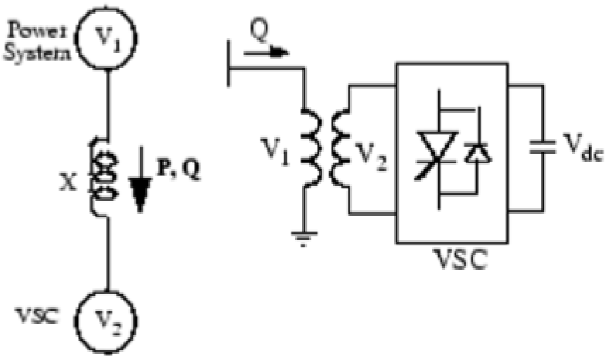


Fig: 1 operating principle of D-statcom.

If the D-STATCOM has a DC source or energy storage device on its DC side, it can supply real power to the power system. This can be achieved by adjusting the phase angle of the D-STATCOM terminals and the phase angle of the AC power system. When phase angle of the AC power system leads the VSI phase angle, the DSTATCOM absorbs the real power from the AC system, if the phase angle of the AC power system lags the VSI phase angle, the D-STATCOM supplies real power to AC system

4. D SATATCOM CONTROLLER

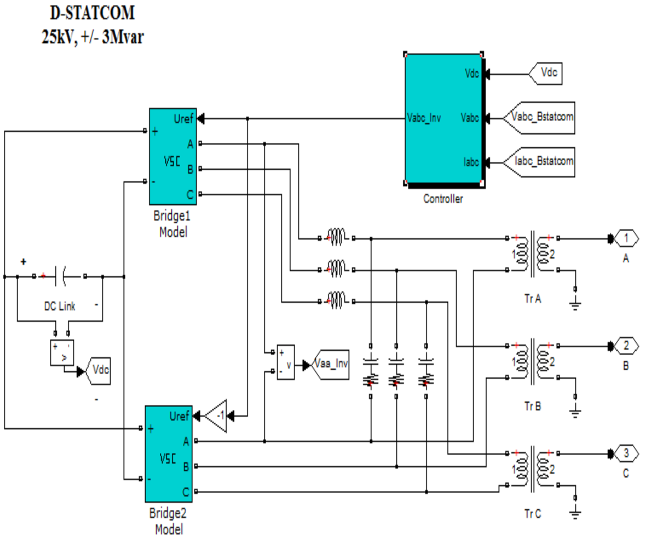


Fig.2 controller

5. SIMULATION BLOCK DIAGRAM OF D-STATCOM

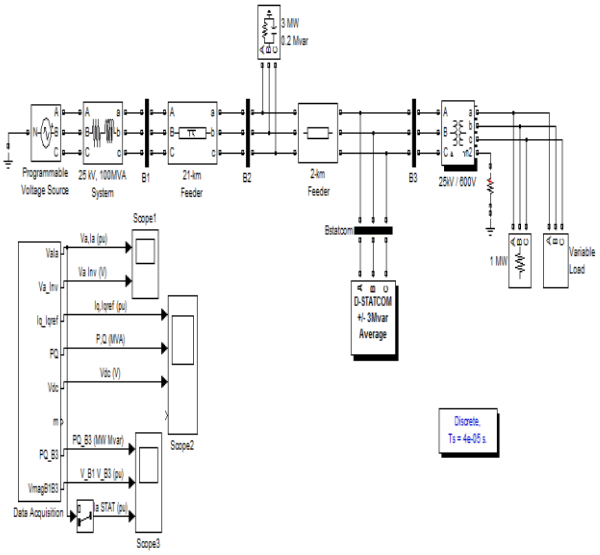


FIG. 3 D-STATCOM SIMULATION

A Distribution Static Synchronous Compensator (D-STATCOM) is used to regulate voltage on a 25-kV distribution network. Two feeders (21 km and 2 km) transmit power to loads connected at buses B2 and B3. A shunt capacitor is used for power factor correction at bus B2. The 600-V load connected to bus B3 through a 25kV/600V transformer represents a plant absorbing continuously changing currents, similar to an arc furnace, thus producing voltage flicker. The variable load current magnitude is modulated at a frequency of 5 Hz so that its apparent power varies approximately between 1 MVA and 5.2 MVA, while keeping a 0.9 lagging power factor. This load variation will allow you to observe the ability of the D-STATCOM to mitigate voltage flicker.

The D-STATCOM regulates bus B3 voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-sourced PWM inverter. When the secondary voltage is lower than the bus voltage, the D-STATCOM acts like an inductance absorbing reactive power. When the secondary voltage is higher than the bus voltage, the D-STATCOM acts like a capacitor generating reactive power

The D-STATCOM consists of the following components:

- **A 25kV/1.25kV coupling transformer** which ensures coupling between the PWM inverter and the network.
- **A voltage-sourced PWM inverter**. In this example, the PWM inverter is replaced on the AC side with three equivalent voltage sources averaged over one cycle of the switching frequency (1.68 kHz). Harmonics generated by the inverter are therefore not visible with this average model. On the DC side, the inverter is modeled by a current source charging the DC capacitor. The DC current Idc is computed so that the instantaneous power at the AC inputs of the inverter remains equal the instantaneous power at the DC output
  P= (Va*Ia + Vb*Ib + Vc*Ic = Vdc*Idc).
- **LC damped filters connected** at the inverter output. Resistances connected in series with capacitors provide a quality factor of 40 at 60 Hz.
- **A 10000-microfarad capacitor** acting as a DC voltage source for the inverter.
- **A voltage regulator** that controls voltage at bus B3.
- **Anti-aliasing filters** used for voltage and current acquisition.

The D-STATCOM controller consists of several functional blocks:

- **A Phase Locked Loop (PLL)**. The PLL is synchronized to the fundamental of the transformer primary voltages.
- **Two measurement systems**. Vmeas and Imeas blocks compute the d-axis and q-axis components of the voltages and currents by executing an abc-dq transformation in the synchronous reference determined by sin (wt) and cos(wt) provided by the PLL.
- **An inner current regulation loop**. This loop consists of two proportional-integral (PI) controllers that control the d-axis and q-axis currents. The controller's outputs are the Vd and Vq voltages that the PWM inverter has to generate. The Vd and Vq voltages are converted into phase voltages Va, Vb, Vc which are used to synthesize the PWM voltages. The Iq reference comes from the outer voltage regulation loop (in automatic mode) or from a reference imposed by Qref (in manual mode). The Id reference comes from the DC-link voltage regulator.

- **An outer voltage regulation loop**. In automatic mode (regulated voltage), a PI controller maintains the primary voltage equal to the reference value defined in the control system dialog box.
- **A DC voltage controller.** which keeps the DC link voltage constant to its nominal value (Vdc=2.4 kV).

The electrical circuit is discretized using a sample time Ts=40 microseconds. The controller uses a larger sample time (4*Ts=160 microseconds).

5.1 D-STATCOM DYNAMIC RESPONSE

During this test, the variable load will be kept constant and you will observe the dynamic response of a D-STATCOM to step changes in source voltage. Check that the modulation of the Variable Load is not in service (Modulation Timing [Ton Toff] = [0.15 1]*100 > Simulation Stop time). The Programmable Voltage Source block is used to modulate the internal voltage of the 25-kV equivalent. The voltage is first programmed at 1.077 pu in order to keep the D-STATCOM initially floating (B3 voltage=1 pu and reference voltage Vref=1 pu). Three steps are programmed at 0.2 s, 0.3 s, and 0.4 s to successively increase the source voltage by 6%, decrease it by 6% and bring it back to its initial value (1.077 pu).

Start the simulation. Observe on Scope1 the phase A voltage and current waveforms of the D-STATCOM as well as controller signals on Scope2. After a transient lasting approximately 0.15 sec., the steady state is reached. Initially, the source voltage is such that the D-STATCOM is inactive. It does not absorb nor provide reactive power to the network. At t = 0.2 s, the source voltage is increased by 6%. The D-STATCOM compensates for this voltage increase by absorbing reactive power from the network (Q=+2.7 Mvar on trace 2 of Scope2). At t = 0.3 s, the source voltage is decreased by 6% from the value corresponding to Q = 0. The D-STATCOM must generate reactive power to maintain a 1 pu voltage (Q changes from +2.7 MVAR to -2.8 MVAR).

5.2 MITIGATION OF VOLTAGE FLICKER

During this test, voltage of the Programmable Voltage Source will be kept constant and you will enable modulation of the Variable Load so that you can observe how the D-STATCOM can mitigate voltage flicker. In the Programmable Voltage Source block menu, change the "Time Variation of" parameter to "None". In the Variable Load block menu, set the Modulation Timing parameter to [Ton Toff] = [0.15 1] (remove the 100 multiplication factor). Finally, in the D-STATCOM Controller, change the "Mode of operation" parameter to "Q regulation and make sure that the reactive power reference value Qref (2nd line of parameters) is set to zero. In this mode, the D-STATCOM is floating and performs no voltage correction.

Run the simulation and observe on Scope3 variations of P and Q at bus B3 (1st trace) as well as voltages at buses B1 and B3 (trace 2). Without D-STATCOM, B3 voltage varies between 0.96 pu and 1.04 pu (+/- 4% variation). Now, in the D-STATCOM Controller, change the "Mode of operation" parameter back to "Voltage regulation" and restart simulation. Observe on Scope 3 that voltage fluctuation at bus B3 is now reduced to +/- 0.7 %. The D-STATCOM compensates voltage by injecting a reactive current modulated at 5 Hz (trace 3 of Scope3) and varying between 0.6 pu capacitive when voltage is low and 0.6 pu inductive when voltage is high.

6. SIMULATION RESULTS

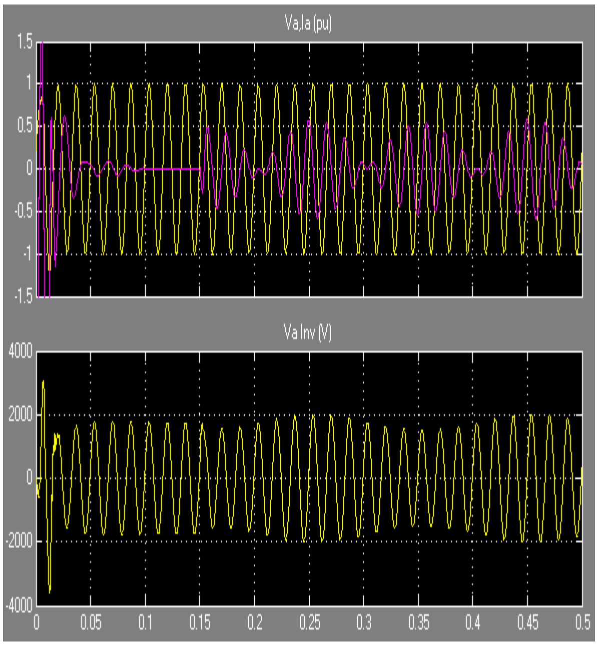
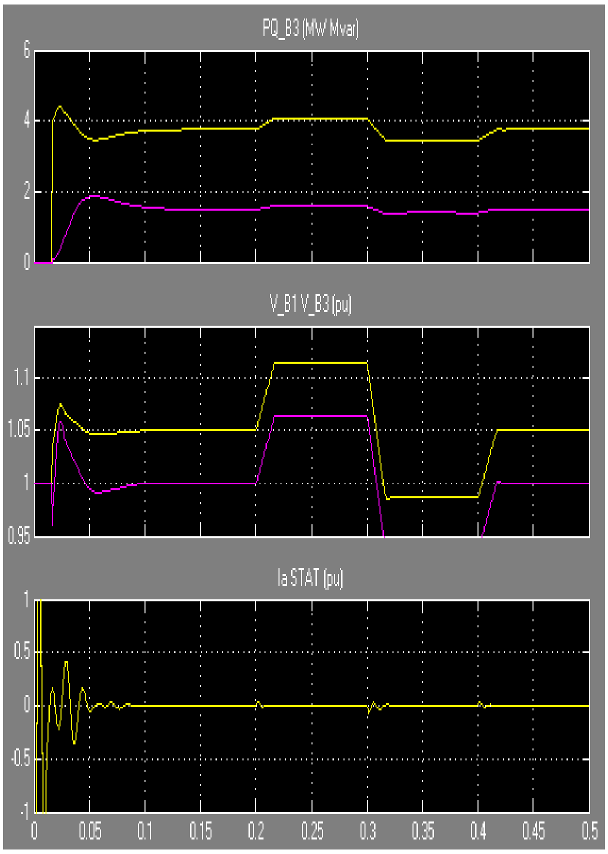


Fig 4. Phase voltage/phase current



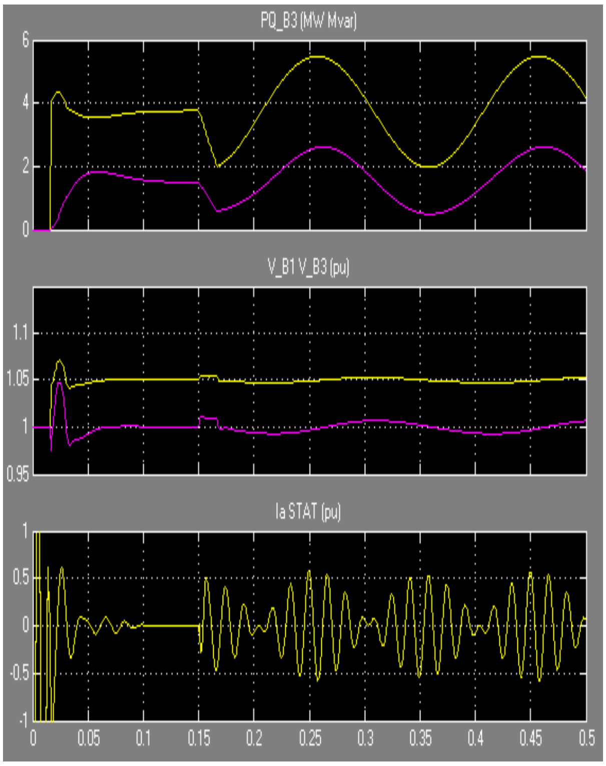


Fig 5. Reduced voltage fluctuation

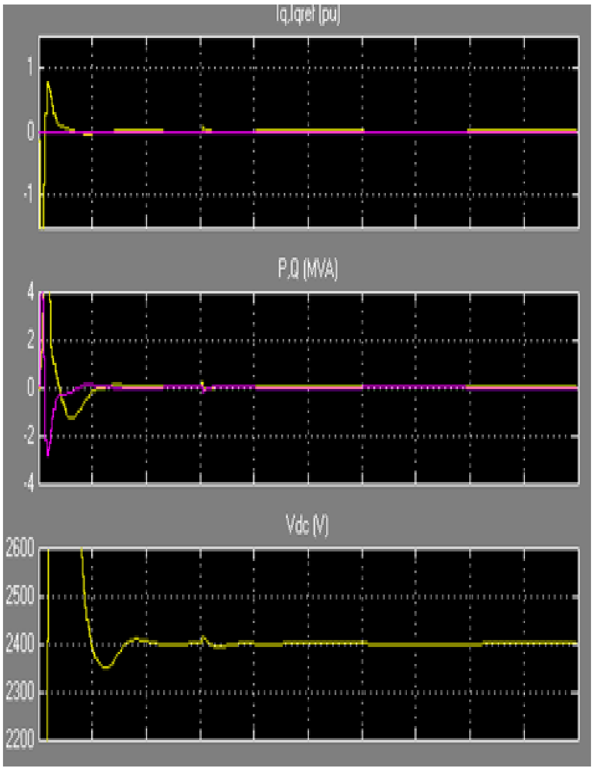


Fig.6 real and reactive power

7. CONCLUSION

Voltage dip and voltage flickering are the two major power quality problems which are frequently seen in the distribution systems. These power quality problems in 25KV, 100 MVA distribution system is investigated in this paper. The analysis and simulation of a DSTATCOM application for the mitigation of power quality problems are presented and discussed. The MATLABPower System Block set simulation results shows that the mitigation of the power quality problems (voltage dip and the voltage flickering) done effectively with D-STATCOM. The voltage got dipped from 1.12 p.u to 0.98p.u for voltage across B1 and 1.06 p.u to 0.94 p.u for voltage across B3 for without D-Statcom and 1.09 p.u to 1.01p.u for voltage across B1 and 1.02 p.u to 0.96 p.u for voltage across B3 with D-Statcom.

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